POLYCULTURES IN AGROFORESTRY

Groeneweg D[1], Vischedijk F[1], Appelman J[2], van Buiten G[3], San Giorgi X[4], Hautier Y[1]*

(1) Ecology and Biodiversity Group, Department of Biology, Utrecht University, The Netherlands (2) Education Institute Biology, Utrecht University, The Netherlands (3) Botanical Gardens, Utrecht University, The Netherlands (4) Food Forestry Development, Utrecht, The Netherlands

*Corresponding author: y.hautier@uu.nl

Abstract

Food forestry could help feeding a growing population in a sustainable way. Growing perennial plant species in polycultures and combining different plant traits could allow complementarity between plant species and thus to produce more yield (overyield) as compared to when the species are grown in monocultures. Morevoer, by mimicking natural systems food forestry could enhance carbon storage and mitigate climate change. Whether food forestry can deliver both overyielding and sustainability is not clear. We set up 28 mesocosms containing either monocultures or polycultures of one tree, one bush and one ground cover species, to assess whether perennial polycultures can produce more biomass than their constituent counterparts while at same time store carbon. After four month of growth we found that biomass production and soil organic carbon increased with diversity. Our results suggest that food forestry could be a sustainable alternative for biomass production.

Keywords: monocultures; polycultures; selection effect; complementarity effect; carbon cycle

Introduction

Solutions must be found to keep feeding a growing population in a sustainable way (Gerland et al. 2014; Tilman 1999; Tilman et al. 2001). By mimicking the structure and relationships of natural forest ecosystems, food forestry could allow us to produce food while preserving the functioning of our ecosystems (Kandji et al. 2006). Additionally, the combination of plant species with different traits, for example a mixture of plants fixing atmospheric nitrogen with plants that do not, could allow complementarity between plant species to produce more yield (overyield) as compared to when the species are grown in monocultures (Loreau and Hector 2001). However, competition between plants for the use of available resources could lead to a reduction of yield (Grace 1993). The current state of research in agroforestry does not allow us to determine whether plant species in mixtures work together or against each other to affect the yield and the functioning of our ecosystems. In this study we investigate whether a polyculture of plants could produce more than its constituent counterparts while preserving ecosystem functioning (https://www.uu.nl/staff/YHautier/0).

In other systems such as grasslands, it has been showed that plant communities with higher diversity can overyield (Cardinale 2012; Hooper et al. 2012), that is, the biomass produced by a species in polyculture is higher when compared to the biomass of that species in a monoculture. Overyielding can come from two different mechanisms: the complementarity effect and the selection effect (Loreau and Hector 2001). Both effects operate in combination and have a different influence on productivity. Complementarity effect includes niche complementarity in which species differ in their resource requirements thus reducing potentail competition between them, and facilitation in which species can modify the environment in a way that benefits other species. Selection effect is the increase in the likelihood of including in the polyculture a species that is highly influencial for biomass production, either positively of negatively, with increasing number of species. Thus the dominance of species with particular traits that affect the ecosystem processes (Loreau and Hector 2001), can increase or counteract complementarity. Currently it is not well understood whether a food forest can overyield and how complementarity and selection effects function in this system. Theoretically it has the potential to produce overyielding, but not enough research has been done to support this theory.

This study is thus designed not only to investigate whether polycultures produce more biomass than monocultures in an agroforestry system, but also to understand the underlying mechanisms and potential impact on the carbon cycle.

Materials and methods

In April 2017, we established mesocosms of 1.2 x 1 x 1 m (l x w x h) in Intermediate Bulk Containers (IBC) in a greenhouse at Utrecht University's Botanical Garden (Figure 1 A). Each mesocosm is filled with two layers of bottom and top soil excavated from a nearby pig farm (Zwolle). Mesocosms contained one of three levels of plant diversity: monocultures of each of three selected species, polycultures of all combinations of two species, and polycultures of all three species (Figure 1 B). Each species composition was replicated four times for a total of 28 mesocosms. Species selection was based on potential complementarity between the three species in terms of acquisition of nutrients and use of canopy space. In particular, we chose the tree species *Toona sinensis*, the nitrogen fixer bush *Cytisus scoparius* and the mineral accumulator ground cover *Achillea millefolium*. We planted the same number of plants for the tree and bush species in each of the monocultures and polycutures. Per mesocosm, we planted three individuals of the tree *T. Sinensis*, eight individuals of the bush *C. Scoparius* and we sowed 1000 seeds *A. millefolium* (Figure 1 C). The experiment will run for a period of minimum five years.

We are measuring a suite of parameters including above and belowground biomass production, nutrient leaching, leaf carbon content, soil organic carbon (SOC), dissolved organic carbon (DOC), and soil respiration.

Aboveground biomass production (g) was assessed after 111 days of growth. *T. sinensis* was measured by harvesting the leaves and cutting the parts of the trees that were higher than 120 cm from the soil. The leaves of each individual were counted. *C. scoparius* was pruned back to the starting size (about 10 cm high). Above ground biomass production of *A. millefolium* was measured by clipping the entire plots at ground level. All the harvested biomass was oven dried at 70°C to constant mass and weighted.

Below ground biomass production (g) was measured by using root ingrowth cores, 74 cm long, with a diameter of 7.5 cm and mesh size of 50 mm. The root ingrowth cores were buried in every mesocosms at the onset of the experiment in March and collected after 116 days. The contents of the cores were sieved, washed, oven dried at 70°C to constant mass and weighted.

Soil samples of the upper 10 cm of the soil were collected every three weeks from the mesocosms between May 9th and July 20th for SOC analysis using an EA/1110 CHNS-O analyser (Interscience BV, Breda, The Netherlands). Water was collected from the taps of the mesocosms, between May 9th and July 20th, and filtrated to measure DOC using a continuous flow auto analyser (Skalar SA-40, Breda, The Netherlands).

Basal soil respiration after 99 days and 126 days of growth in the mesocosms was measured by using a respirometer equipped with carbon dioxide and oxygen sensors (Biometric Systems, Germany).

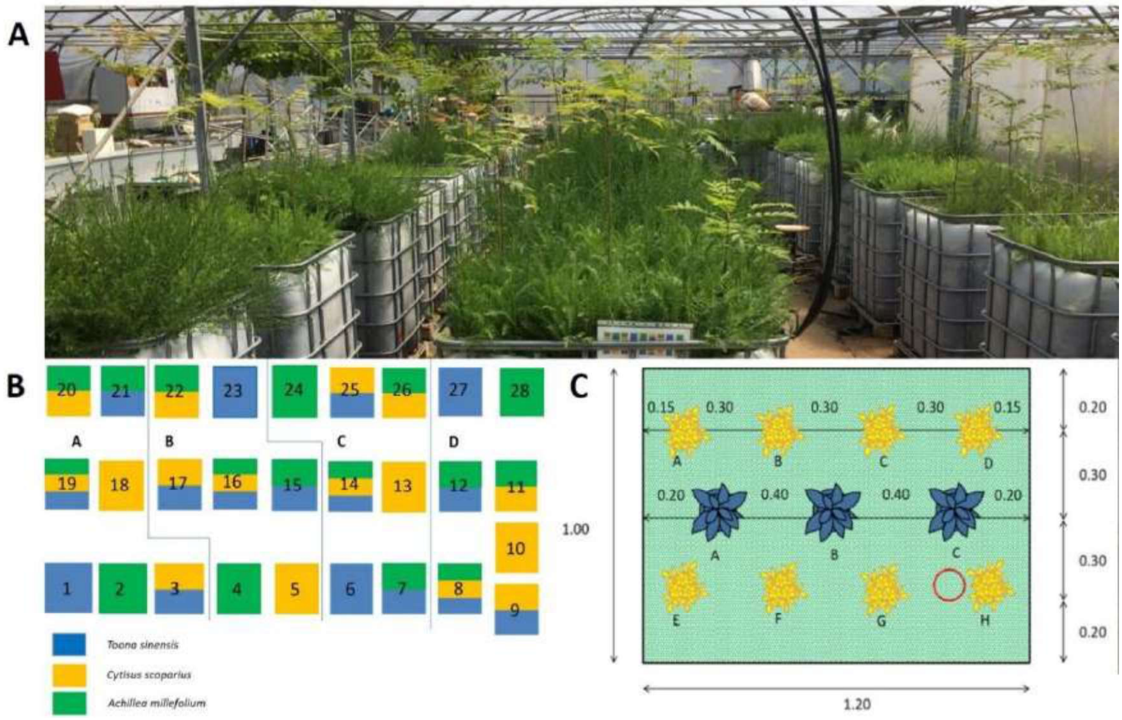

Figure 1: Experimental setup. A) Pictures showing the agroforestry experiment in a greenhouse at Utrecht University Botanical Gardens. B) Setup of the mesocosms, the content of the mesocosms and the distribution of the blocks. C) Setup of the plants in the mesocosm. Numbers indicate distances in metres. The three blue plants in the middle represent the tree *Toona sinensis*, the eight yellow plants represent the bush *Cytisus scoparius* and the green background represents the ground cover forb *Achilea millefolium*.

Results

After the first four months of the experiment, we found that the polycultures of two and three species produced more biomass compared to the monocultures (Figure 2). This overyielding was due to both a complementarity effect and a selection effect. The complementarity effects probably came from complementarity in space (filling up of the different layers in the canopy structure, thus intercepting more light). The selection effect emerged from the highly productive species in monoculture (*Cytisus scoparius*) which was a major determinant of productivity in the polycutures.

On the other hand, both the tree *Toona sinensis* and the bush *Cytisus scoparius* produced more biomass when grown in a monoculture while biomass production of the herb *Achillea millefolium was constant along the diversity gradient.* This result highlights the duality between overyielding at the community level (niche complementarity) and overyielding at the species level (facilitation). None of the species investigated produced more biomass in polycultures, while altogether, polycultures produced more than any of their constituent counterparts grown in monoculture.

Additionally, we found that polycultures contained more soil organic carbon, while monocultures and polycultures did not differ in terms of below ground biomass production, dissolved organic carbon or soil respiration (data not shown).

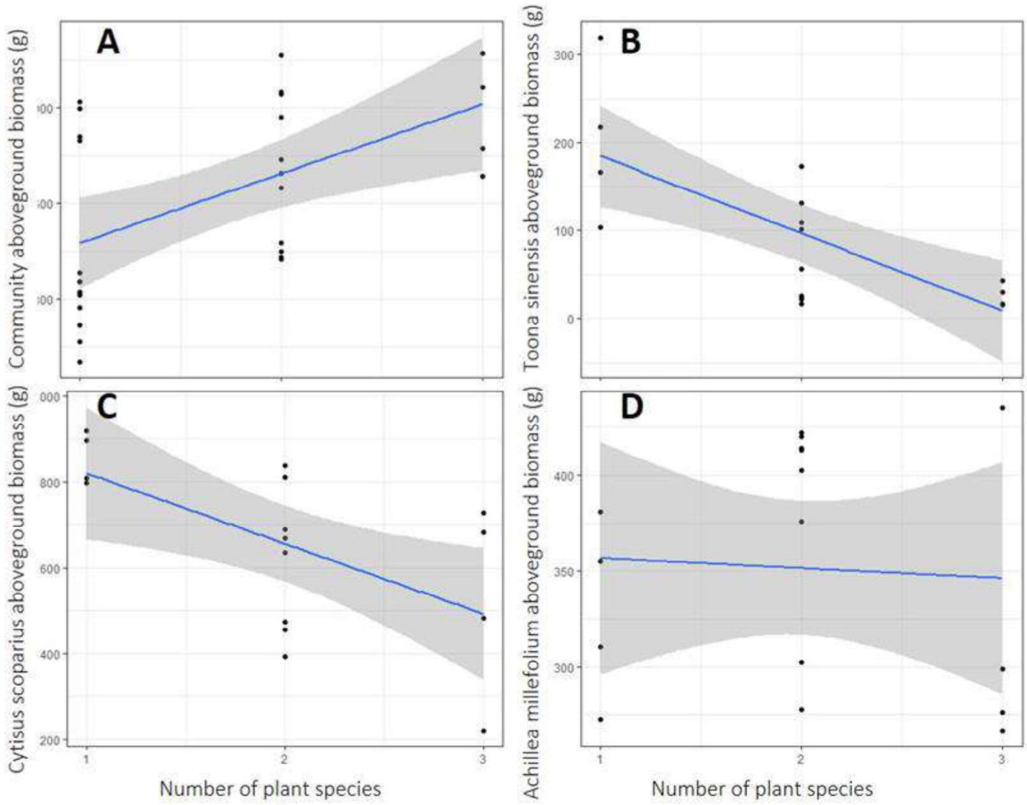

Figure 2: Aboveground biomass after four months of growth of A) all plant species, B) all *Toona sinensis*, C) all *Cytisus scoparius* and D) all *Achillea millefolium* in each mesocosm along the manipulated plant diversity gradient.

Discussion

Our results showed an increase in above ground biomass with an increase in species richness. This result is in line with studies conducted in grasslands (Cardinale 2012; Hooper et al. 2012). This was due to both a complementarity and selection effect. Despite the increase in above ground biomass production with higher species richness we did not find a difference of below ground biomass production with higher species richness.

Because we found more above ground biomass in which carbon can be stored with higher species richness, we can say that polycultures appear to have the potential to store more carbon in their above ground biomass compared to monocultures. This was also found by other studies in which large amounts of carbon were stored in plant biomass, especially in forests (Luyssaert et al. 2008). We found no significant relation of soil respiration or DOC leakage with an increase in species richness. A neutral effect of species richness on soil respiration was also found by De Boeck et al. (2007) who determined the impact of grassland plant diversity on respiration rates. We did find a slight but significant increase in SOC with an increase in species richness (data not shown). This agrees with previous evidence that polycultures have a higher potential to sequester carbon than monocultures (Nair et al. 2009; Richards et al. 2010). Since our results are from the very first stages of a food forest systems, we expect to have clearer results with more factors contributing to SOC in the next five years. Furthermore, the findings depend on the species (composition) and will probably be different with different species or different number of species. For example, tree plantation monocultures can become a carbon sink if the right species and managemental practices are chosen (Freibauer et al. 2004; Sharrow and Ismail 2004).

Conclusion

We found that polycultures produced more above ground biomass and contained more SOC. However, monocultures and polycultures did not differ in terms of below ground biomass production, DOC or respiration. Our results suggest that food forest systems have the potential to overyield and store more carbon compared to monocultures.

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